RESEARCH DEPARTMENT

SOME PROBLEMS INFLUENCING THE DESIGN OF A MACHINE FOR THE HIGH-SPEED DUBBING OF MAGNETIC RECORDINGS

Report No. C-081

(1954/4)

W Proctor Wilson

P.E. Axon, O.B.E., Ph.D., M.Sc., A.M.I.E.E.

(W. Proctor Wilson)

This Report is the property of the British Broadcasting Corporation and may not be reproduced or disclosed to a third party in any form without the written permission of the Corporation.

Report No. C-081

SOME PROBLEMS INFLUENCING THE DESIGN OF A MACHINE FOR THE HIGH-SPEED DUBBING OF MAGNETIC RECORDINGS

Section	Title	Page
1	INTRODUCTION	1
2	FUNDAMENTAL CONSIDERATIONS	1
3	HIGH-SPEED REPRODUCING AND RECORDING CHAINS	2
	3.1. The Reproducing Head	2
	3.2. The Recording Head	3
	3.3. Amplifiers	3
	3.4. Erasure	4
4	MECHANICAL CONSIDERATIONS	4
	4.1. General	4
	4.2. The Feed-Spool Systen	5
	4.3. Take-Up Spool System	5
	4.4. The Slipping Clutch	6
	4.5. Re-Winding Facilities	7

Report No. C-081

(1954/4)

SOME PROBLEMS INFLUENCING THE DESIGN OF A MACHINE FOR THE HIGH-SPEED DUBBING OF MAGNETIC RECORDINGS

1. INTRODUCTION

With the full introduction of magnetic recording into the Broadcasting Service a need may arise for the duplication of tape recordings for purposes of programme exchange or distribution by the Transcription Service. Report No. C-080, recently issued by this Department, describes an investigation of the contact printing process as a possible means of high-speed duplication. The experiments in that investigation were concerned with the fundamental aspects of the magnetic transfer process, a knowledge of which would enable the desirable properties of the master and slave tapes to be specified. The investigation showed that although the method is not without promise, it cannot yet produce recordings which, for practical purposes, are comparable with those produced by a direct magnetic recording. It is clear, for example, that a slave tape will be required possessing magnetic properties superior to those of any tape now available, and these properties are unlikely to be achieved in the near future. The contact printing process has, therefore, no immediate application in the Service.

The purpose of this report is to give an appreciation of some of the problems which will be met with in an alternative approach to tape duplication by the process of high-speed multi-tape dubbing. This appreciation is based, in so far as the magnetic recording aspects are concerned, on recent work carried out in Research Department on the recording and reproduction of magnetic tapes at speeds of the order of 100 in./sec. It will appear in the course of the discussion that the magnetic recording problems arising in the high-speed dubbing process can be effectively overcome by modern technique and that the remaining problems are mainly those of mechanical design. These mechanical design problems have not been investigated in any detail since the investigation of high-speed recording was not devoted primarily to the dubbing process. A discussion of the problems will be given, however, and the experience gained in the experiments will be quoted where relevant.

2. FUNDAMENTAL CONSIDERATIONS

When a magnetic recording is made on a normal machine of professional type the range of audio frequencies recorded may lie between 30 c/s–15 kc/s and the tape speed used will be the primary standard of 15 in./sec or one of the secondary standard speeds of 30 and 7½ in./sec. The tape speed, S, and the range of frequencies (f_1 to f_2) used will define the range of wavelengths (S/f_1 to S/f_2) recorded on the tape. Suppose now that a recording made at 15 in./sec (the speed most likely to be used) is reproduced at a tape speed of 100 in./sec. Since the wavelengths on the tape have been established in the recording process it follows that the frequencies reproduced will be related to those originally recorded by a multiplying factor

100/15, and the time taken to replay the recording will be reduced by the factor 15/100. If the output from this high-speed reproducing process were to be dubbed on another tape moving at 100 in./sec, the wavelengths obtained on the second tape would be the same as those existing on the first. Thus, when the second tape is reproduced at 15 in./sec, the range of frequencies obtained will be reduced by the factor 15/100, i.e. the range and its limits will be identical to the original recording signals and the time taken to reproduce the whole tape will equal the time taken to record the original. Thus the duplication of the original tape could be achieved in a duplicating period less than one sixth of the original recording time. Clearly, then, high-speed dubbing could provide a speedy method of duplication if the reproducing and re-recording chains could be adapted to the high frequencies involved and if simultaneous dubbing of many tapes could be arranged. In effect the adaption of the reproducing and re-recording chains is the principal magnetic and electronic problem, whilst the simultaneous dubbing of many tapes is the principal mechanical problem.

3. HIGH-SPEED REPRODUCING AND RECORDING CHAINS

3.1. The Reproducing Head

The highest speed at which the multi-tape dubbing process can be carried out depends on the highest frequency which can be handled by the reproducing and re-recording chains. In general, however, the higher the speed used, the more complicated will the mechanical design become and the longer will be the time required to set up the machine, with all tapes in position for the dubbing process. Clearly, there would be little advantage in a design in which, for example, fifteen minutes were required to set up the machine to dub six tapes in ten seconds if an alternative and simpler design existed, in which the machine could be set up in five minutes to dub the same six tapes in five minutes. Experience in this Department indicates that a tape speed of 100 in./sec does not entail any exceptional precautions in the driving and spooling arrangements for the tape, nor does it involve unacceptable wear of the tape itself. This discussion will therefore assume the use of a dubbing speed of 100 in./sec so that a thirty minute recording can be duplicated in something less than five minutes. If the range of audio frequencies recorded on the original is from 15 c/s to 15 kc/s, the equivalent range involved in the duplicating process is from 200 c/s to 100 kc/s.

The use of a conventional reproducing head for the reproduction of frequencies in the upper part of this band would entail eddy-current losses which are higher than those normally met with. If these were serious it would be possible to replace the conventional laminated core by a ferrite core such as "Ferroxcube" — a sintered, non-conducting magnetic material which, although of lower permeability than mu-metal, has negligible eddy-current losses. Ferroxcube is now available in a core-shape and grade intended for use in miniature magnetic recording and reproducing heads. In this form coils may be wound upon two halves of a core which may be clamped or stuck together with a suitable low-temperature resinous product such as "Araldite". Ferroxcube is an extremely hard, brittle material, and cannot be machined so that it must be ground and polished at the pole tips to produce the required finish. This property of extreme hardness is of great value in the present application in which high tape speeds and, therefore, increased abrasion, are encountered. On the other hand, the brittleness and hardness make it more difficult to obtain a reproducing gap which is as perfectly formed and finely finished as that which can be obtained with a mu-metal core. The choice of mu-metal or Ferroxcube for the reproducing-head core therefore depends on an evaluation of the relative losses which may occur from eddy-current effects in the mu-metal core and from possible imperfect gap-formation in the Ferroxcube core. Experiments made in the laboratory indicate that the wavelength response of the two types can (with some care) be made almost identical in the range under discussion, and that the eddy-current losses at the highest frequency in a mu-metal core of 5 mil laminations are smaller (only about 3·5 dB) than expected. Taking into account, therefore, the superior wearing properties of the ferrite head, it is probably true to say that this will be the better type to use, although the verdict in favour is a fairly narrow one in this frequency and wavelength range.

3.2. The Recording Head

In the high-speed recording process the range of frequencies which must be recorded, equivalent to the audio-spectrum, lie between 200 c/s and 100 kc/s as before. In addition, however, an h.f. bias current must be added to the recording signal and this must bear approximately the same relation to the original bias frequency as the (200 c/s–100 kc/s) band does to the audio band. If the original bias frequency is of the order of 100 kc/s, then the bias frequency employed in the high speed recording process must be about 1 Mc/s. The losses involved in using this frequency in a conventional mu-metal recording head would be quite prohibitive so that the substitution of Ferroxcube for mu-metal as the recording-head core becomes a necessity. It follows, of course, that the gap of the recording head must be prepared and finished as carefully as possible, in order that no anomalous alignment effects occur in reproduction, due to recording-gap irregularities.

3.3. Amplifiers

It is obvious that monitoring of the tapes being recorded in the dubbing process is of no value, first because all the original recording frequencies have been multiplied by a factor of 100/15 and, secondly, because most of the recording band lies outside the audio-spectrum. No provision need be made in the apparatus, therefore, for monitoring heads or monitoring amplifiers. In practice, then, only one signal amplifier is required for the high-speed dubbing process, consisting of a stage (or stages) for the reproduction of the original tape, which feeds into a number of power stages in parallel, each leading to one recording head. Into each recording head circuit must also be fed the bias current required and this may conveniently be taken from a bias distribution amplifier with a number of parallel outputs equal to the number of recording heads. This bias distribution amplifier may be fed from a single oscillator of conventional design.

The design of the recording amplifier carrying the high frequency recording signals is obviously more complex than a normal recording amplifier, since the bandwidth it is required to handle is much wider and this introduces attendant problems of noise. On the other hand, satisfactory designs for amplifiers involving these frequencies and bandwidths have been evolved in this Department and are being employed in other applications. A bias distribution amplifier, similar to that which will be required, is also in use. In all cases, of course, since the "audio" frequencies lie from 200 c/s upwards, the elimination of hum is a matter of greater simplicity than in a normal audio amplifier.

3.4. Erasure

The multiple dubbing machine should preferably be used in conjunction with a tape-laundry system, so that no erasure facilities for the tapes need be provided on the machine. The erasing frequency required, if such facilities were to be provided, would be the same as the bias, i.e. about 1 Mc/s. As in the recording case, the use of a ferrite head would be essential, but the 1 Mc/s power required for satisfactory erasure would be much greater. Another property of ferrites, which is relevant to this consideration, is their very poor thermal conductivity. Now although the eddy-current losses are negligible at 1 Mc/s, appreciable losses, which appear in the form of heat, may arise from hysteresis. Consequently, large powers in a ferrite head involve appreciable heating and the poor thermal conductivity makes it difficult to carry this heat away by conduction cooling. In extreme cases the temperature may reach the Curie point so that the magnetic field decreases with further increase of current. To avoid this condition, convection cooling of the head may be necessary. This would involve the supply of a blower unit. Thus it is obviously preferable to avoid, if possible, the necessity for erasure upon the apparatus.

4. MECHANICAL CONSIDERATIONS

4.1. General

The elements of a system by which the high speed dubbing process could be carried out simultaneously on many tapes are shown in Fig. 1. The reels of tape, wound in their spools, are mounted on a common shaft, X, and are driven past heads, A, B, C, D, etc. by the common driving capstan, S, which is mounted in suitable bearings and end-driven by a motor. Each tape is kept in contact with the driving capstan by a rubber idler. After passing the driving shaft, the tapes are wound up into the take-up spools, which are mounted on a common shaft, Y, also end-driven by a spooling motor. No motor is necessary on the feed-spool shaft, X, which need only be suitably braked to provide the necessary tension over the heads.

Tape 1 might be the previously recorded master, so that A is a reproducing head, the output of which is fed, after suitable amplification and with an addition of high frequency bias, into the recording heads B, C and D. The use of a common uniform capstan S, and a single driving motor, makes the apparatus effectively independent of reasonable variations in the driving speed. The wavelengths on tape 1 having been previously established, the same wavelengths are bound to be recorded on tapes 2, 3 and 4, provided that any speed variations occur in all the tapes at the same time.

In practice, this simple system will need no extensive modifications except in the design of the feed-spool and take-up spool systems. The modifications required in these elements present problems which, however, whilst probably capable of solution, have not previously been covered in the literature.

The simple feed and take-up systems shown in the figure will be quite unsuitable in practice for the following reasons. First, it is certain that no set of reels mounted on the shaft X will contain, initially, exactly the same amount of tape. Consequently, the diameter on which the outer layer of tape is lying will be different in each reel. From the commencement of operation, then, each spool on the shaft X will be required to rotate at a slightly different rate, with respect to the other spools, to deliver tape at the rate of 100 in./sec specified by the driving capstan. Secondly, after the initial setting-up, or threading, process has been carried out on the machine by an operator, it is unlikely that the diameter on which the outer layer of tape is lying will be the same in any of the take-up spools. Again, then, from the commencement of operation, the various spools on the shaft Y will be required to rotate at slightly different rates in order to collect the tape at a common, even tension, as it is delivered from the driving system at 100 in./sec. It is clear that in either case a simple shaft to which each spool is rigidly locked would prove quite unsuitable in practice, for after a short time some tapes would be quite slack, whilst others would be approaching breaking tension.

4.2. The Feed-Spool System

The provision of an independent and controlled supply of tape from each feed spool, whilst maintaining the advantages of compactness inherent in a common shaft system, should be the less difficult of the two requirements to meet. The outline of one possible solution is shown in Fig. 2. Pairs of disks A_1 and A_2, B_1 and B_2, etc. are mounted on the common shaft, round which they may rotate, and each pair is separated from the adjacent pair by a suitable distance. The outer diameter of each disk is such that the inner diameter of the N.A.B. spool can just pass over it. Each of the disks has three projections which fit into the three driving grooves at the centre of the N.A.B. spool. Between the disks A_1 and A_2, at opposite ends of the diameter, are two ball spring catches. These ball spring catches enable A_1 and A_2 to be lightly locked in either of two positions, in one of which the projections on both disks are in alignment and in one of which they are separated by an angle of 60°. Similar ball spring catches exist between disks B_1 and B_2 and between C_1 and C_2, etc. To mount the spools on the shaft, the projections on each pair of disks are brought into alignment and the first spool is threaded down over all of them until it reaches the bottom one C_2 on which it rests, the projections of C_1 fitting into the driving grooves. Disk B_2 is then turned through 60° with respect to B_1 and locked in this position. When the next spool is then passed down the shaft it will be brought to a stop by the projections on B_2, whilst the projections of B_1 will fit into its driving grooves. This process may be carried on until the shaft is full. It is clear that in this system, each pair of disks, with their associated spool, may rotate round the shaft independently of any other pair.

To provide the independent braking of each spool, a fairly simple system may be adopted in the form of a light spring-loaded arm, on the end of which is mounted a felt pad. One of these arms rests on the outer layer of tape in each reel and provides a frictional drag which may, by suitable design, be easily adjusted to the required magnitude and made constant over the whole radius of travel. The tape is pulled out of each spool by the driving system so that if a tape breakage occurs between the feed spool and the driving system, the brake will automatically stop the rotation of the spool. Thus no danger exists of tape being thrown out on the feed side.

4.3. Take-Up Spool System

The solution of the problems inherent in a common shaft for the take-up system are much more difficult. If only one or two multiple dubbing machines are required, and only a reasonable number of tapes (of the order of, say, six) is required to be dubbed simultaneously, it will probably be more profitable to avoid the solution of these difficult problems altogether by designing a machine in which each take-up spool is mounted on a separate shaft and driven by a separate spooling motor. This of course, will mean that rather more space is occupied by the reels on the take-up side, but this should not be excessive if only about six reels are envisaged. The tension in the tape between each take-up spool and the driving system will then be determined by a suitable choice of spooling motor, as in a conventional recording system. The use of separate motors and shafts will eliminate all the difficulties connected with the differing speeds of rotation which may be required for the various spools and will also have advantages if tape breakage should occur between the driving system and any take-up spool. It is obviously quite possible to arrange, by a suitable microswitch and tape-guide system, that each spooling motor is supplied with power so long as its associated tape is running at the correct tension between two chosen points. Should a breakage occur, and this tension disappear, power would be switched from the motor, whilst the particular rubber idler which is holding this tape in contact with the driving shaft would be tripped. The spools concerned then come to a stop on both the feed and take-up sides. In this way the possibility of a tape breakage on the take-up side destroying a whole operation or wasting a whole reel of tape would be eliminated.

4.4. The Slipping Clutch

If a common take-up shaft, driven by a single spooling motor were required, then it would be necessary to incorporate in the central element which is supporting each N.A.B. spool, a form of slipping clutch. This would rotate synchronously with the common shaft as long as the tape tension was within a safe limit, but would slip on the shaft if this limit were exceeded. The slipping clutch is known in a mechanical form, making use of spring tensions, and in a magnetic form, as embodied in the magnetic fluid clutch. In either case, the clutch must be built within some system of the type described for the common feed shaft in paragraph 4.2, to enable all the reels to be mounted on the single shaft.

In a possible form of mechanical slipping clutch, two or more blade springs might be attached to each of the spacers A_3, B_3 and C_3 in Fig. 2, which would be rigidly attached to the driven shaft. The blade springs would press down upon the upper disks A_1, B_1 and C_1 in each case. The pressure of the blade springs resting on any one disk would make it rotate with the shaft as long as the tension of the tape being reeled up into the spool was equal to, or less than, some previously chosen value. If, owing to differences of starting radii in the spools, it was necessary that a particular spool rotate at a different speed from the shaft, then this would manifest itself as an excessive tension in the tape being spooled. The pressure of the blade springs would be such that this excessive tension would cause the clutch to slip so that spooling was continued only at a rate which maintained the tension at a safe value. At every stage the clutch associated with each disk should slip or rotate with it according to the requirements of the tension.

In practice of course, it is fundamentally impossible for this, or any other such simple system to work perfectly. To illustrate this let P be the total pressure of the blade springs in any one clutch on the disk below them and let y be the radius of the points of contact of the springs on this disk. If f is the tension in the tape and x the radius of the outer layer of the tape then slipping will take place when $xT = \mu Py$ where μ is the coefficient of friction between the blade springs and the disk. The tension T at which slip takes place will thus depend on the radius x, so that if the pressure P is adjusted for the condition when a large amount of tape is on the reel, excessive tensions will be accepted without slipping when only a few layers are wound up. Clearly a compromise must be introduced so that a safe tension exists for conditions near the centre of the wheel without excessive slipping taking place when the reel becomes more full. The slipping tension might be kept within reasonable limits over the whole reel by a form of equalisation consisting of a suitable choice of the speed/torque characteristic of the spooling motor. This same problem exists of course, on the take-up side of a conventional tape recorder and should, ideally, be corrected in this case also by a suitable speed/torque characteristic in the motor. In practice, however, such a refinement is rarely found in commercial machines which still function fairly well. Clearly then, some degree of latitude is possible in the solution of this particular aspect of the problem.

A similar problem would exist in the design of a magnetic fluid clutch together with a more serious problem of tailoring the design to the small volume available in the centre of the N.A.B. spool. In the fluid clutch, of course, an elegent solution is possible, for it would be feasible to arrange that the current which energised it varied in accordance with the radius of the outer layer of tape upon the reel, so that an almost constant slipping tension could be attained over the whole radius of the reel.

It must be concluded, however, that if only a small number of machines, operating at the reasonable tape speed of 100 in./sec were required, the development required to perfect either form of clutch, might more profitably be avoided as described in paragraph 4.3.

4.5. Re-Winding Facilities

If re-winding facilities are required on the apparatus, the common feed shaft must be replaced by a set of re-spooling motors equivalent to the motors on the take-up side, or alternatively, by a common spooling shaft similar to that just discussed in connection with the take-up mechanism. An examination of the requirement leads to the conclusion that, in fact, re-winding facilities do not justify the expense of providing them. A simple artifice can be introduced to render the lack of re-winding facilities comparatively unimportant if the master tape is wound up backwards before placing on the machine and is replayed in this way in the multiple dubbing process. At the end of the operation all the slave tapes will then be in the correct direction for replaying and may be taken off the machine ready for use. The master tape must be rewound again in the opposite direction, on another machine, only if another set of dubbings is required.

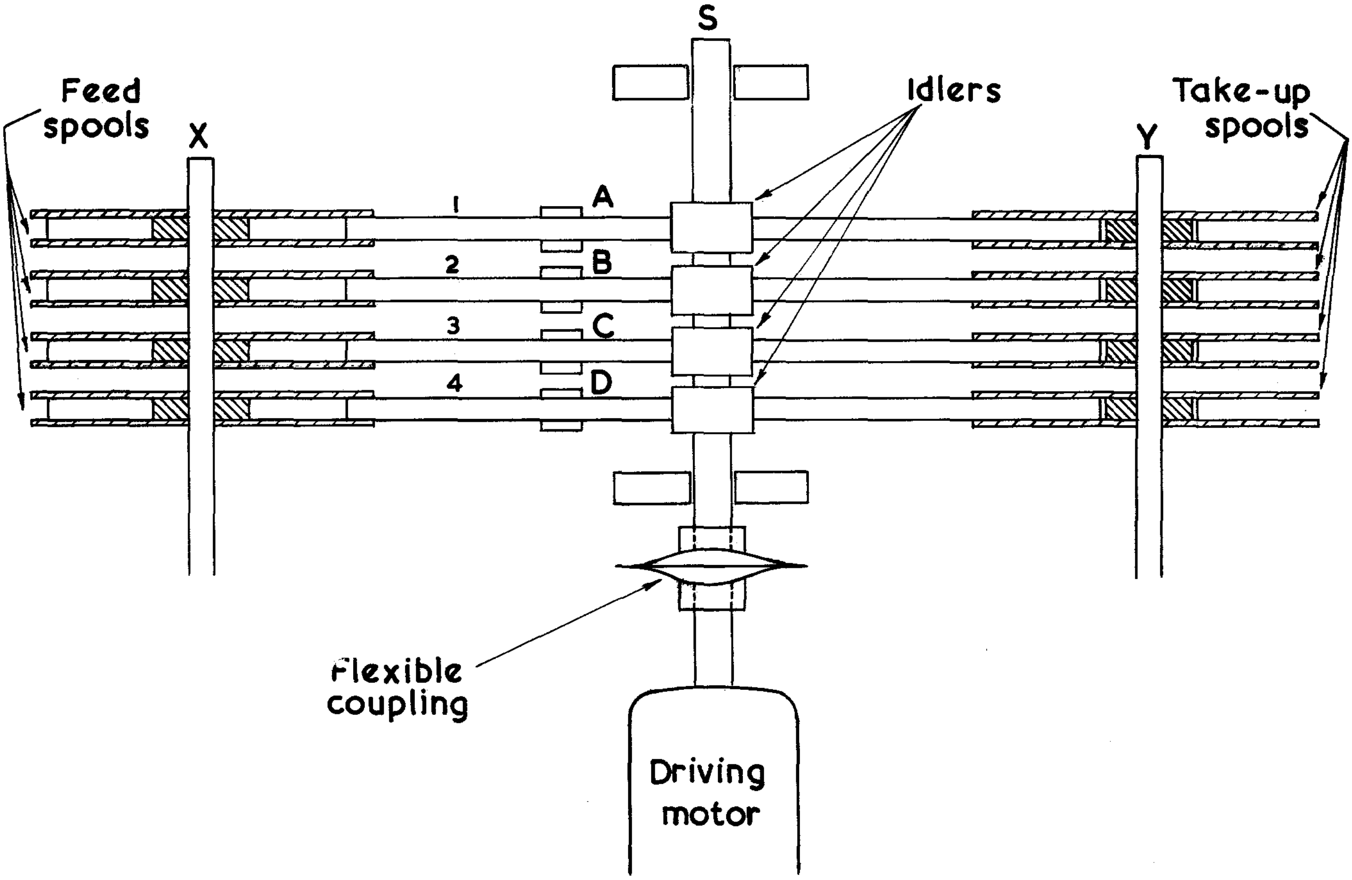

Fig. 1

Idealised diagram of mechanical arrangements in high speed dubbing machine

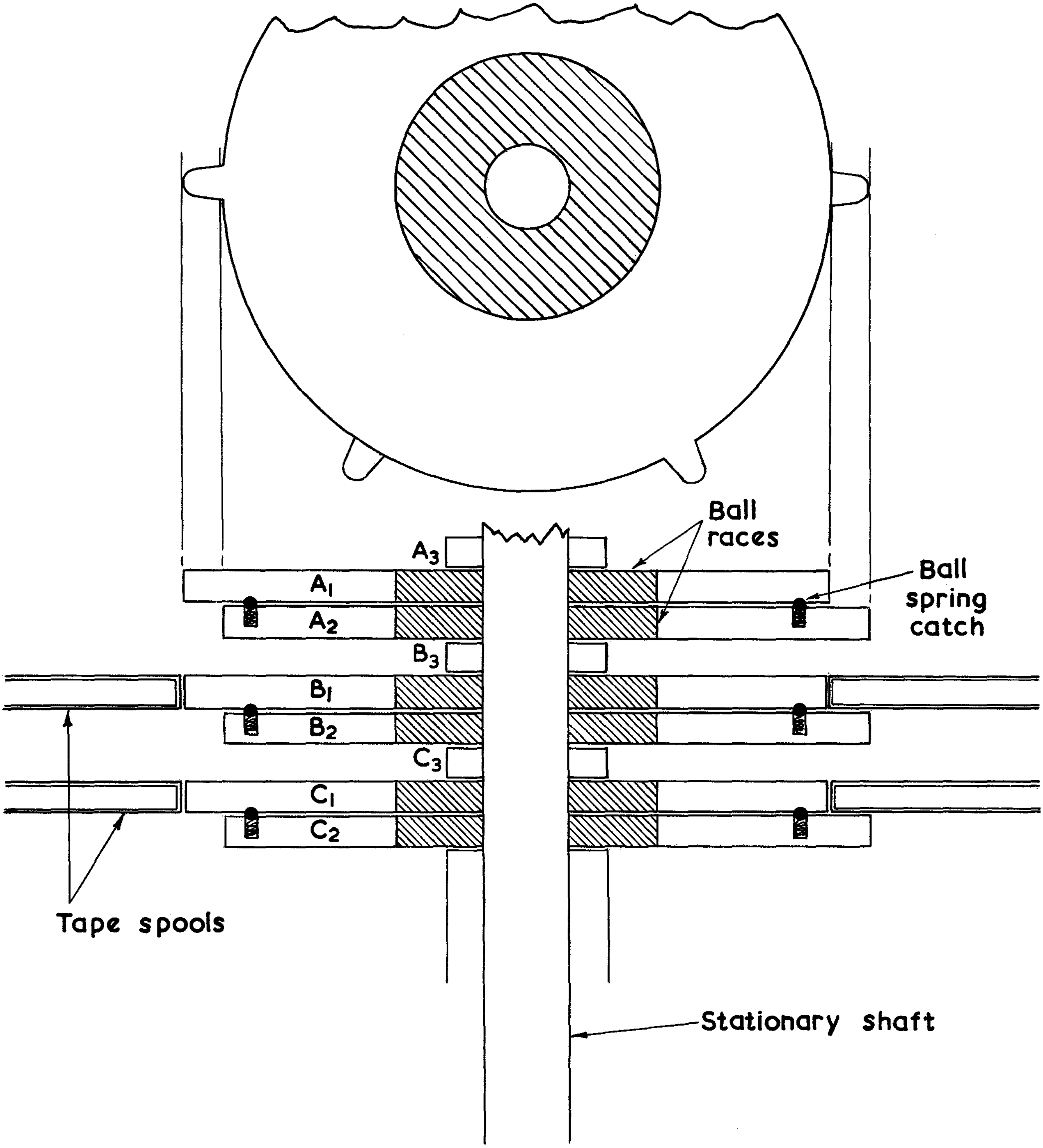

Fig. 2

A possible form of common shaft for feed spools